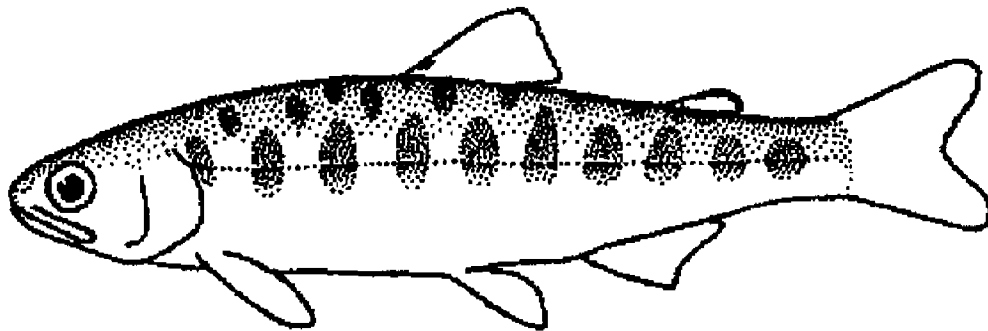
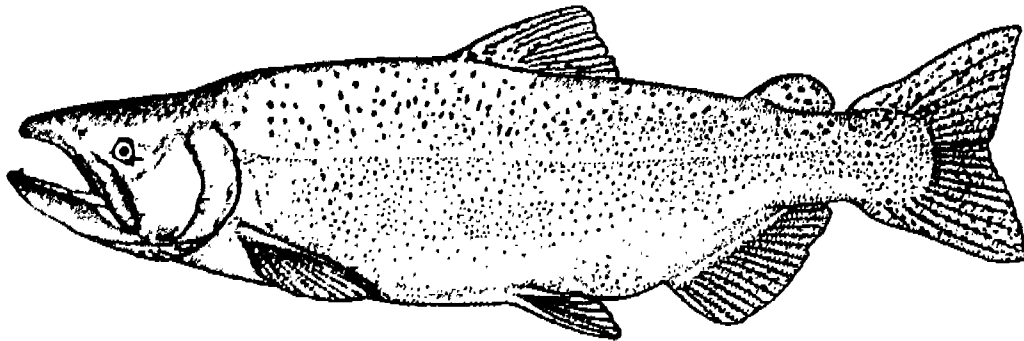


**MONITORING OF RESTORATION PROJECTS IN CLEAR CREEK USING
2-DIMENSIONAL MODELING METHODOLOGY**



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PREFACE

This report was prepared as part of the Clear Creek Restoration Project Monitoring Investigations, a 3-year effort which began April 1999. Title 34, section 3406(b)(12) of the Central Valley Project Improvement Act, P.L. 102-575, authorizes funding for channel restoration of Clear Creek to provide spawning, incubation, and rearing habitat for salmon and steelhead. The purpose of this investigation is to evaluate the success of these restoration activities.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

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INTRODUCTION

The decline of spring and fall-run chinook salmon and steelhead trout in Clear Creek over the last decade is attributed to many factors including habitat degradation. The existing habitat appears inadequate for either spawning or rearing. The Central Valley Project Improvement Act (CVPIA), section 3406(b)(12), authorizes funding for channel restoration of Clear Creek to provide spawning, incubation, and rearing habitat for salmon and steelhead. In response to this authorization, in 1998 the U.S. Fish and Wildlife Service (Service) developed the Lower Clear Creek Flood Plain Restoration Project to increase spawning success on the section of Clear Creek downstream of Saeltzer Dam. Part of this study proposal included the use of the Service's Instream Flow Incremental Methodology (IFIM) to compare total weighted usable area (WUA) of salmonid habitat before and after channel restoration utilizing 2-D modeling. The Clear Creek Study is a 3-year effort that will be completed in two phases (pre-restoration and post-restoration) in 2005, depending on the schedule of restoration construction. This report addresses the first phase, and modeling of the plan for the post-restoration conditions.

A 2-D hydraulic and habitat model (RIVER2D) was used for this modeling, instead of the Physical Habitat Simulation (PHABSIM¹) component of the Instream Flow Incremental Methodology (IFIM). The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the downstream end of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since data is collected uniformly across the entire site. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's Equation and a velocity adjustment factor. Other advantages of 2-D modeling are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions. The model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model, with compact cells, will be more accurate than PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity, substrate and cover. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

¹ PHABSIM is the collection of one dimensional hydraulic and habitat models which are used to predict the relationship between physical habitat availability and streamflow over a range of river discharges.

METHODS

Study Site Selection

In April 1999, four study sites were selected for the pre-restoration phase of the study within the 2-mile-long restoration area on lower Clear Creek. Each of these sites were evaluated based on morphological and channel characteristics at the up- and downstream end of each site which facilitate the development of reliable hydraulic models, and on their overall representation of the mesohabitat types present within the entire restoration site. A side channel site (Site 3) was included within the study area because most of the side channel habitat originally present in Clear Creek will be eliminated during restoration activities². The characteristics of the study sites are given in Table 1. Data collection for the pre-restoration phase of the study was completed by February 2001, with data analysis from that work resulting in this report.

Table 1
Characteristics of Study Sites

Site Name	Site length (ft)	Mean site width (ft)	Mean site bed slope
Site 1	791	99	0.49%
Site 2	803	191	0.13%
Site 3	344	69	0.24%
Site 4	1094	141	0.15%

Transect Placement (study site setup)

The pre-restoration study sites were established in April and May 1999. For each study site, a transect was placed at the up- and downstream ends of the site. The downstream transect was modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 900 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

² Although the post-restoration plan does not include any side channel habitat, the first in-channel post-restoration phase includes some side channel habitat as a result of channel changes caused by high flow releases from Whiskeytown Dam in April 2003.

Hydraulic and Structural Data Collection

Vertical benchmarks were established at each site to serve as the reference elevation to which all elevations (streambed and water surface) were tied. In addition, horizontal benchmarks were established at each site to serve as reference locations to which all horizontal locations (northings and eastings) were tied. Fluvial geomorphologists for the restoration project established total station control points and staff gage locations previous to the start of our IFIM work. Our vertical and horizontal benchmarks were tied into these points.

The data collected at the upstream (transect 2) and downstream (transect 1) transects include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at three different stream discharges (except on site 1) using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a high-to-mid range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Table 2 gives the substrate codes and size classes used in this study. Table 3 gives the cover codes and categories used in this study.

We collected the data between the up- and downstream transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate were visually assessed at each point. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site. The number and density of points collected for each of the pre-restoration study sites is given in Table 4. Substrate and cover along the transects were also determined visually. To validate the velocities predicted by the 2-D model, depth, velocity, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[®] model 2000 velocity meter or a Price AA velocity meter equipped with a current meter digitizer at the low flow. These validation velocities and the velocities measured on the transects described previously were collected at 0.6 of the depth for 20 seconds. The horizontal locations and bed elevations were determined by taking a total station shot on a prism held at each point where depth and velocity were measured. A minimum of 50 representative points were measured per site.

Hydraulic and structural data collection began in April 1999 and was completed in July 1999. Site 1 water surface elevations were collected at a low (141 cfs) and medium (235 cfs) flow. At site 2, water surfaces elevations were collected at four flows (145, 244, 329, and 425 cfs). Water surface elevations were collected at site 3 at four flows (2.7, 16.0, 27.3, and 40.2 cfs). The reduced nature of these flows was due to site 3 being located in a side channel. Water surface elevations were collected at three flows (112, 216, and 404 cfs) for site 4. The reason that fewer water surface elevations were collected at sites 1 and 4 relative to sites 2 and 3 were the result of the latter two sites being set-up earlier than sites 1 and 4. Sites 2 and 3 were both set-up on April 7, 1999. Site 4 was set-up on April 13, 1999, and site 1 was not set-up until May 12, 1999.

Table 2
Substrate Descriptors and Codes

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 - 1
1.2	Medium Gravel	1 - 2
1.3	Medium/Large Gravel	1 - 3
2.3	Large Gravel	2 - 3
2.4	Gravel/Cobble	2 - 4
3.4	Small Cobble	3 - 4
3.5	Small Cobble	3 - 5
4.6	Medium Cobble	4 - 6
6.8	Large Cobble	6 - 8
8	Large Cobble	8 - 10
9	Boulder/Bedrock	> 12
10	Large Cobble	10 - 12

The later set-up of sites 1 and 4 prevented measurement of water surface elevations for some of the higher flows measured for sites 2 and 3 due to the declining nature of the hydrograph. Data collection in the study sites was difficult at times because some areas were too deep at certain flows to get measurements and yet the creek is too small to allow for the use of a jet boat. Discharge measurements were collected at all sites under at least two different flow levels, while wading with a wading rod equipped with a Marsh-McBirney^R model 2000 velocity meter or a Price AA velocity meter equipped with a current meter digitizer. At sites 2 and 3 discharge measurements were collected at four different flow levels.

Hydraulic Model Construction and Calibration

All data were compiled and checked before entry into PHABSIM data files. A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical (e.g, if the substrate size class was 2-4 inches on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the

Table 3
Cover Coding System

Cover Category	Cover Code ³
no cover	0
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
overhead cover (> 2' above substrate)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

Table 4
Number and Density of Data points Collected for Each Site

Site Name	Number of Points	Number of Points	Density of Points
Pre-restoration	on Transects	Between Transects	(points/100 m ²)
Site 1	63	437	6.89
Site 2	56	526	4.07
Site 3	91	267	16.25
Site 4	92	368	3.22

³ In addition to these cover codes, we have been using composite cover codes (3.7, 4.7, 5.7 and 9.7); for example, 4.7 would be branches plus overhead cover.

WSEL of the highest flow to be modeled. An ASCII file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton) to get the PHABSIM input file and then translated into RHABSIM⁴ files.

All of the measured WSELs were checked showing that there was no uphill movement of water. For the pre-restoration study sites, a total of four WSELs were used for site 2 and site 3. Three WSELs were used for site 4. Two WSELs were used for site 1.

Calibration flows in the data files (Appendix A) were the flows measured at site 2, which included the entire flow of Clear Creek. Flow/flow regressions were performed for sites 1, 3 and 4, since they did not include the entire flow, using the flow measured at each site and the total river flow, measured at site 2. The regressions were developed from two to four sets of flows, with the entire river discharge at 145 cfs, 244 cfs, 329 cfs and 425 cfs. Calibration flows for sites 1, 3 and 4 were calculated from the total discharge and the appropriate regression equation in Table 5.

Table 5
Flow/Flow Regression Equations

Pre-restoration Study Site	Regression Equation ⁵	R ² -value
1	Site 1 $Q = 3 + 0.95 \times Q$	1 ⁶
3	Site 3 $Q = -17 + 0.13 \times Q$	0.999
4	Site 4 $Q = -39 + 1.04 \times Q$	0.99999

The slope for each transect was computed at each measured flow as the difference in WSELs between the two transects divided by the distance between the two. The slope used for each transect was calculated by averaging the slopes computed for each flow. A separate deck was constructed for each study site.

The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. However, if the upstream transect contains a lower bed elevation than the

⁴ RHABSIM is a commercially-produced software (Payne and Associates 1998) that incorporates the modeling procedures used in PHABSIM.

⁵ Q is the total river flow, Site 1 Q is the flow in Site 1, etc.

⁶ Since there were only two flows available to use in this regression, the R²-value, by definition, was one.

downstream transect, the SZF for the downstream transect applies to both. For downstream transects with backwater effects, the SZF value was measured by determining, using differential leveling, the highest bed elevation on the thalweg downstream of the site. For sites where the hydraulic control for the upstream transect was located within the site, the SZF (the thalweg elevation at the hydraulic control) was determined from the bed topography data collected for the 2-D model.

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous *et al.*, 1989) was run on the files for sites 2 to 4 to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the geometry of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects. *IFG4*, the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot difference between measured and simulated WSELs⁷. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

For a majority of the transects in the pre-restoration study sites, *IFG4* met the above criteria (Appendix A). *MANSQ* worked successfully for the two transects in site 1 and for the two lowest flows for the downstream transect in site 3, meeting the above criteria for *MANSQ* (Appendix A). We were unable to use *IFG4* for site 1 since we only had two water surface elevations to use in calibration. The final step in simulating WSELs was to check whether water was going uphill at any of the simulated WSELs. This did not occur for any of the study sites.

Velocity Adjustment Factors (VAFs) were examined for all of the simulated flows (Appendix B). None of the pre-restoration study site transects deviated significantly from the expected pattern of VAFs. In addition, VAF values (ranging from 0.11 to 2.40) were all within an acceptable range

⁷ The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion is our own.

except for the lowest flow at both transects within site 4.⁸ The low VAF values for the above site are due to strong backwater effects caused by a long riffle downstream of the site, and is acceptable in this case since RHABSIM is only being used to simulate WSELs and not velocities.

For the pre-restoration sites, the dry/shallow total station data and the PHABSIM transect data were combined in Quattro pro to create the input files (bed, substrate and cover) for the 2-D modeling program. An artificial extension one channel-width-long was added upstream of the top of the site to enable the flow to be distributed by the model when it reached the study area. For the post-restoration plan, the bed topography was exported out of a dxf file provided by McBain and Trush Consultants through Arc-View into a Quattro pro spreadsheet to create the input files (bed, substrate and cover) for the 2-D modeling program⁹.

The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the substrate and cover files contain the horizontal location, bed elevation and, respectively, the substrate and cover code for each point. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 6, with the bed roughness value computed as the sum of the substrate bed roughness value and the cover bed roughness value. The bed roughness values for substrate in Table 6 were computed as five times the average particle size¹⁰. The bed roughness values for cover in Table 6 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover-type. The bed, substrate and cover files were exported from Quattro pro as ASCII files.

A utility program, R2D_BED (Steffler 2001b), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines¹¹ going up the channel along features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation. The bed topography of the sites is shown in Appendix C. R2D_BED was also used interactively to assign substrate, cover and bed roughness values to the post-restoration plan files, assuming that pools had a substrate code of 0.1,

⁸ VAFs are considered acceptable if they fall within the range of 0.2 to 5.0.

⁹ Since no field data could be collected for the post-restoration plan, there was no PHABSIM modeling, as above, for the post-restoration plan.

¹⁰ Five times the average particle size is approximately the same as 2 to 3 times the d85 particle size, which is recommended as an estimate of bed roughness height (Yalin 1977).

¹¹ Breaklines are a feature of the R2D_Bed program which force the TIN of the bed nodes to linearly interpolate bed elevation and bed roughness values between the nodes on each breakline and force the TIN to fall on the breaklines (Steffler 2001b).

Table 6
Initial Bed Roughness Values¹²

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05	9	0.29
10	1.4	9.7	0.57
		10	3.05

riffles had a substrate code of 1.3, areas below the 200-300 cfs water surface elevation had a cover code of 0.1, and areas above the 200-300 cfs water surface elevation had a cover code of 3.7.

An additional utility program, R2D_MESH (Steffler 2001a), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the River2D model. R2D_MESH uses the final bed files as an input. The first stage in creating the computational mesh

¹² For substrate code 9, we used bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2. Bed roughnesses of zero were used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

was to define mesh breaklines¹³ which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and then additional nodes were added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Steffler 2001a). The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. As shown in Appendix D, the meshes for all sites had QI values of at least 0.3. In addition, the difference in bed elevation between the mesh and final bed file was less than 0.1 foot (0.03 m) for most of the area of all sites. For the pre-restoration sites, the percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes ranged from 87% to 98%. In contrast, the plan had 59% of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes. In most cases, the areas of the mesh where there was greater than a 0.1 foot (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file within 1.0 foot (0.3 m) horizontally of the bed file location. Given that we had a 1-foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file. The final step with the R2D_MESH software was to generate the computational (cdg) files.

The cdg files were opened in the RIVER2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughnesses of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of RIVER2D is given in Ghanem et al (1995). For the pre-restoration sites, the computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by RIVER2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the upstream transect. In this study, where the highest simulated flow was much greater than the highest flow at which WSELs were measured, we initially tried to calibrate River2D using the WSELs simulated by PHABSIM, since we felt that any inaccuracies in the PHABSIM simulated WSELs were more than countered by the increased accuracy of calibrating the 2-D model at the highest flow to be simulated. For the post-restoration plan, the computational mesh was run to steady state at a flow of 259 cfs, and the WSELs predicted by RIVER2D at the upstream end of the site were compared to a WSEL measured at the upper end of the first post-restoration area (which corresponded to the top of the post-restoration plan) at the same flow¹⁴. For the downstream WSEL for this calibration, we used

¹³ Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Steffler 2001a). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

¹⁴ This was based on the assumption that the WSEL at the top of the first post-restoration area was controlled by the channel conditions within the first post-restoration area.

the WSEL predicted by River2D at 259 cfs in pre-restoration study site 1 at the location of the downstream end of the post-restoration design. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. We were unable to calibrate the cdg file for site 2 at the highest simulated flow. We concluded in this case that the PHABSIM extrapolation of the WSELs, beyond the range of measured WSELs, at the upstream transect was inaccurate. Thus it was better to calibrate River2D at the highest flow at which a water surface elevation was measured (425 cfs). In addition, the side channel present in site 2 resulted in a strongly expanding flow that created an unstable flow pattern with changing eddies and flow paths. To help stabilize the solution, eddy viscosity was increased. Of the three eddy viscosity coefficient parameters in the River2D model (epsilon1, epsilon2, and epsilon3), increasing the epsilon3 value is the most physically justified and focused on the eddies (Peter Steffler, personal communication). The epsilon3 value was increased incrementally from the default value of 0.1 used for the other study sites to 0.3 to attain a stable solution.

A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2001). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than one¹⁵. Finally, the WSEL predicted by the 2-D model should be within 0.1 foot (0.031 m) of the WSEL measured at the upstream transect¹⁶. The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites less than 1%, with the exception of site 2 with a net Q of 1.5% (Appendix D). The calibrated cdg file for site 1, site 2, site 4 and the post-restoration plan had a maximum Froude Number of greater than one (Appendix E). We considered the solutions for all sites to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the site having Froude Numbers less than one. A high Froude Number at a very limited number of nodes would be expected to have an insignificant effect on the model results. For all of the pre-restoration sites, the calibrated cdg files had WSELs that were within 0.1 foot (0.031 m) of the measured WSELs (Appendix D). In contrast, the post-restoration plan had a WSEL that was less than the measured WSEL by as much as 0.17 foot (0.052 m). We concluded that the WSEL calibration of the post-restoration site was acceptable, given that there were significant differences between the topography of the plan and that of the first post-restoration area at the time that the WSEL was measured,¹⁷ and given the assumption that the WSEL at the upstream end of the first post-restoration site was controlled by conditions within this site, rather than by conditions downstream in the pre-restoration area.

¹⁵ This criteria is based on the assumption that flow in low gradient streams is usually subcritical, where the Froude number is less than one (Peter Steffler, personal communication).

¹⁶ We have selected this standard because it is a standard used for PHABSIM (U. S. Fish and Wildlife Service 2000).

¹⁷ We observed significant changes in the topography of the first post-restoration area as a result of high flows in April of 2003 associated with a gloryhole spill from Whiskeytown Reservoir.

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by RIVER2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were both those measured at the up- and downstream transects and the 50 measurements taken between the transects. See Appendix E for velocity validation statistics. Although there was a strong correlation between predicted and measured velocities, there were significant differences between individual measured and predicted velocities. In general, the simulated and measured cross-channel velocity profiles at the up- and downstream transects (Appendix E¹⁸) were relatively similar in shape. Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection, (2) the effect of the velocity distribution at the upstream boundary of the site, (3) operator error during data collection, i.e., the probe was not facing precisely into the direction of current, and (4) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations.

River2D distributes velocities across the upstream boundary in proportion to depth, so that the fastest velocities are at the thalweg. In contrast, the bed topography of a site may be such that the fastest measured velocities may be located in a different part of the channel. Since we did not measure the bed topography upstream of a site, this may result in River2D improperly distributing the flow across the upstream end of the site. As discussed above, we added artificial upstream extensions to the sites to try to address this issue.

The 2-D model integrates effects from the surrounding elements at each point. Thus, point measurements of velocity can differ from simulated values simply due to the local area integration that takes place. As a result, the area integration effect noted above will produce somewhat smoother cross-channel velocity profiles than the observations.

Overall, the simulated velocities for site 1 were relatively similar to the measured velocities for both cross sections, with some differences in magnitude that fall within the expected amount of natural variation in velocity. Measured velocities on the south side of cross section one that are lower than the simulated velocities can be attributed to errors in the bed file likely resulting from insufficient data to accurately capture the bed topography. Bed elevations used in the 2-D model that may have been higher than those that actually existed for that portion of the channel upstream of cross section one appear to have decreased the amount of flow to a greater extent than actually occurred in that area.

A majority of the simulated velocities on cross section one in site 2 were relatively similar to the measured velocities, with some differences in magnitude that fall within the expected amount of natural variation in velocity. Measured velocities on the south side of cross section one that are

¹⁸ Velocities were plotted versus easting for transects that were orientated primarily east-west, while velocities were plotted versus northing for transects that were orientated primarily north-south.

lower and higher than the simulated velocities can be attributed to errors in the bed file likely resulting from insufficient data to accurately capture the bed topography. In reality, a boulder or other feature blocking flow upstream of cross section one may have resulted in the zero measured velocity value. The feature blocking the flow likely diverted additional flow along the south bank, resulting in the first measured velocity along that bank being higher than the simulated value.

As with cross section one, a majority of the simulated velocities on cross section two of site 2 were relatively similar to the measured velocities, with some differences in magnitude that fall within the expected amount of natural variation in velocity. Measured velocities on the north side of cross section two that are higher than the simulated velocities can be attributed to the effect of the velocity distribution at the upstream boundary of the site. This resulted in a relatively uniform distribution of velocities in the model, whereas in reality the topography upstream of cross section two may have caused more water to be distributed on the north side of the channel, resulting in the higher measured velocities on that side of the cross section.

In site 3, the simulated velocities on cross section one were relatively similar to the measured velocities with some differences in magnitude that fall within the expected amount of natural variation in velocity, with the exception of the lower velocities at the north end of the transect. This area of the channel was braided, making it difficult to accurately capture the bed topography. The greater complexity of this site would have required a greater density of survey points to accurately capture the bed topography. It appears that the 2-D model was constructed for that area of the site such that the topography limited the amount of flow into that section of the cross section to a greater degree than occurred with the actual bed topography.

The site 3 simulated velocities on cross section two also were relatively similar to the measured velocities with some differences in magnitude that fall within the expected amount of natural variation in velocity, again with the exception of the north side of the transect. However, in this situation, it appears that the higher simulated velocities on the north side of the channel can be explained by a significant protrusion of the bank on the north side of the channel that was upstream of cross section two and therefore was not present in the 2-D model. The influence of this protruding bank is reflected in the reduced magnitude of the measured velocities for the north side of the transect.

Cross section one in site 4 had simulated and measured velocities that were comparably similar, the differences in magnitude within the range of expected variation. This was also true for most of cross section two in site 4, with the exception of the south end of the transect. The lower simulated velocities in that portion of the cross section can be attributed to a protrusion of bedrock present upstream of cross section two that decreased the measured velocities at that point. A review of the substrate and depth for that portion of the transect showed that, while the depths on the transect in that area had not decreased, the recorded substrate was bedrock. Because the bedrock protrusion existed upstream of cross section two and was outside the modeled site, the simulated velocities do not reflect its influence on the velocities for that portion of the transect.

The flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydraulics of the sites at the simulation flows (50 cfs to 300 cfs by 25 cfs increments and 300 cfs to 900 cfs by 50 cfs increments for sites 1, 2 and 4 and the post-restoration plan). Because site 3 was located in a side channel that required flows of at least 150 cfs to become inundated, the flow and downstream WSEL in the calibrated cdg file were changed by 25 cfs increments for flows 150 cfs to 300 cfs and by 50 cfs increments for flows 300 cfs to 900 cfs. The cdg file for each flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow for the pre-restoration sites and the WSEL predicted by River2D for pre-restoration site 1 at the downstream location of the plan for the post-restoration design. Each cdg file was run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions should usually have a Max F of less than one. The production cdg files all had a solution change of less than 0.00001, but the net Q was greater than 1% for one flow for site 1, five flows for site 2, six flows for site 3, one flow for site 4, and two flows for the post-restoration plan (Appendix F). We still considered these sites to have a stable solution since the net Q was not changing and the net Q in all cases was less than 5%, with the exception of two flows for the post-restoration site (7.2% to 7.6%¹⁹) and one flow for site 3 (8.3 %). In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. The maximum Froude Number was greater than one for all of the simulated flows for sites 1 and 2 and for the post-restoration plan, 0 out of 19 simulated flows for site 3, and 20 out of 23 simulated flows for site 4 (Appendix F); however, we considered these production runs to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the area within the site having Froude Numbers less than one.

Habitat Suitability Criteria (HSC) Development

The HSC for fall-run chinook salmon spawning and fry and juvenile rearing used in this study were those developed from Sacramento River data. See U.S. Fish and Wildlife Service 2003 and 2005 for details.

¹⁹ River2D has two options for specifying the boundary conditions at the downstream boundary: either specifying the WSEL (fixed downstream WSEL condition) or using a depth-unit discharge relationship (variable downstream WSEL condition) (Steffler and Blackburn 2001). The fixed downstream WSEL condition resulted in unacceptably high net Q's (77.7% - 89.7%) for the lowest two flows for the post-restoration plan (Appendix F). We concluded that it was better to use the variable downstream WSEL condition for these flows, since the simulation error associated with errors in the downstream WSEL was much less than the simulation error associated with the high net Q's.

Habitat Simulation

The final step was to simulate available habitat for each site for fall-run chinook salmon spawning and fry and juvenile rearing. Preference curve files for spawning and rearing were created containing the digitized HSC developed for the Sacramento River fall-run chinook salmon (Appendix G). RIVER2D was used with the final cdg files, the substrate file and the preference curve file to compute spawning WUA for each site over the desired range of flows (50 cfs to 300 cfs by 25 cfs increments and 300 cfs to 900 cfs by 50 cfs increments for sites 1, 2 and 4). For site 3, spawning WUA was computed for flows 150 cfs to 300 cfs by 25 cfs increments and by 50 cfs increments for flows 300 cfs to 900 cfs. This process was repeated to compute the fry and juvenile rearing WUA using RIVER2D with the final cdg files, the cover file and the fry and juvenile rearing preference file, with the addition of a final step using an ArcMap post-processor to incorporate the adjacent velocity criteria. The fall-run chinook salmon adult spawning and fry and juvenile rearing WUA values calculated for each site are contained in Appendix H. The total spawning WUA values for the study reach were not calculated by simply totaling up the WUA values for each site for each flow. Rather, separate substrate files for each habitat unit within the study sites were created by referencing aerial photos where the habitat units were delineated. The final cdg files and the preference file were used with these substrate files to calculate the WUA values for each habitat unit for each flow. Using the habitat typing data from the aerial photos, the total area for each habitat type within the reach was calculated, along with the total area for each habitat type in the four modeled sites within the reach. For each habitat type, the WUA of the habitat units of that type within the four modeled sites were then added together. The resulting total for each habitat type was then multiplied by the ratio of the total area for that habitat type within the reach to total area of that habitat type within the modeled sites to arrive at the total WUA for that habitat type within the reach. The total reach WUA was then calculated by adding together the total reach WUA values for each habitat type. The same process was used with the cover files to arrive at the total reach WUA for fry and juvenile rearing.

RESULTS

The flow habitat relationships for fall-run chinook salmon spawning in the pre-restoration reach and the post-restoration plan are shown in Figure 1. These results indicate that the post-restoration plan will result in a significant increase in fall-run chinook salmon spawning habitat at all flows, as compared to the pre-restoration conditions, and that the flow with the maximum WUA will shift from 150 cfs under the pre-restoration conditions to 175 cfs under the post-restoration plan. At the current spawning flows of 200 cfs, we modeled a 382% increase in spawning habitat due to the restoration project.

The flow habitat relationships for fall-run chinook salmon fry rearing in the pre-restoration reach and the post-restoration plan are shown in Figure 2. These results indicate that the post-restoration plan will result in a significant increase in fall-run chinook salmon fry rearing habitat at flows ≤ 150 cfs, but a decrease in fry rearing at higher flows, as compared to the pre-restoration conditions. The latter effect could be alleviated by incorporating features such as large woody debris and small alcoves, which have high suitability for fry rearing, into the post-restoration plan.

Figure 1
Fall-run Chinook Salmon Spawning Flow-Habitat Relationships

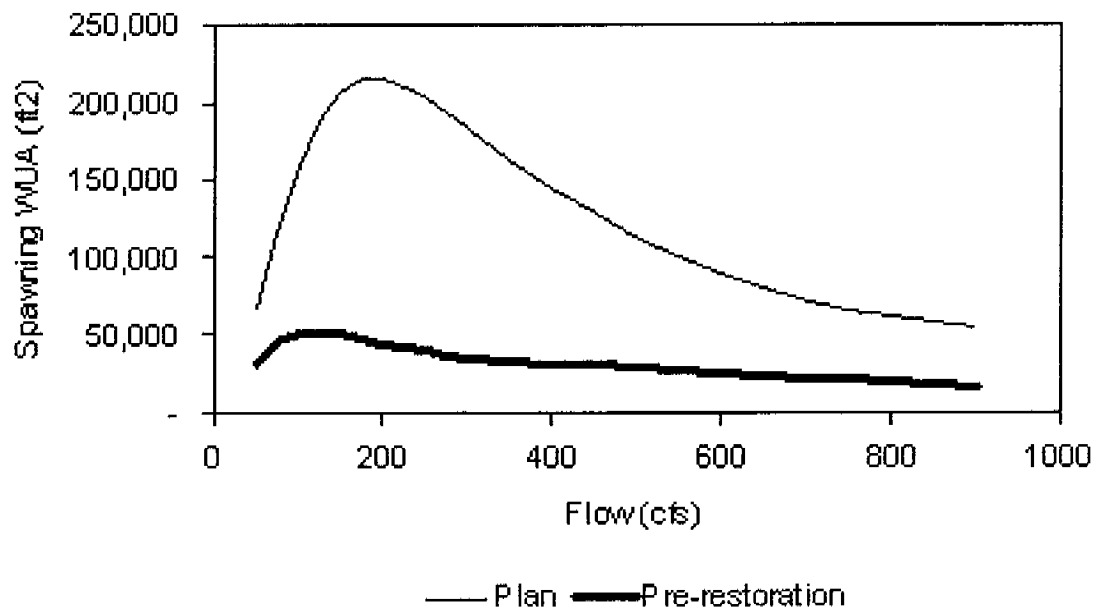
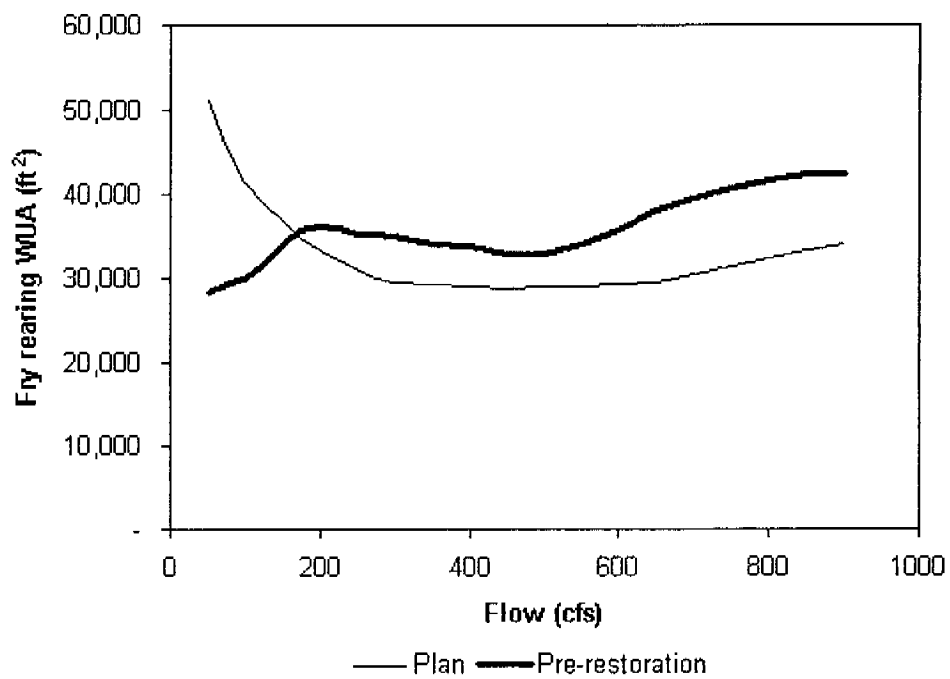
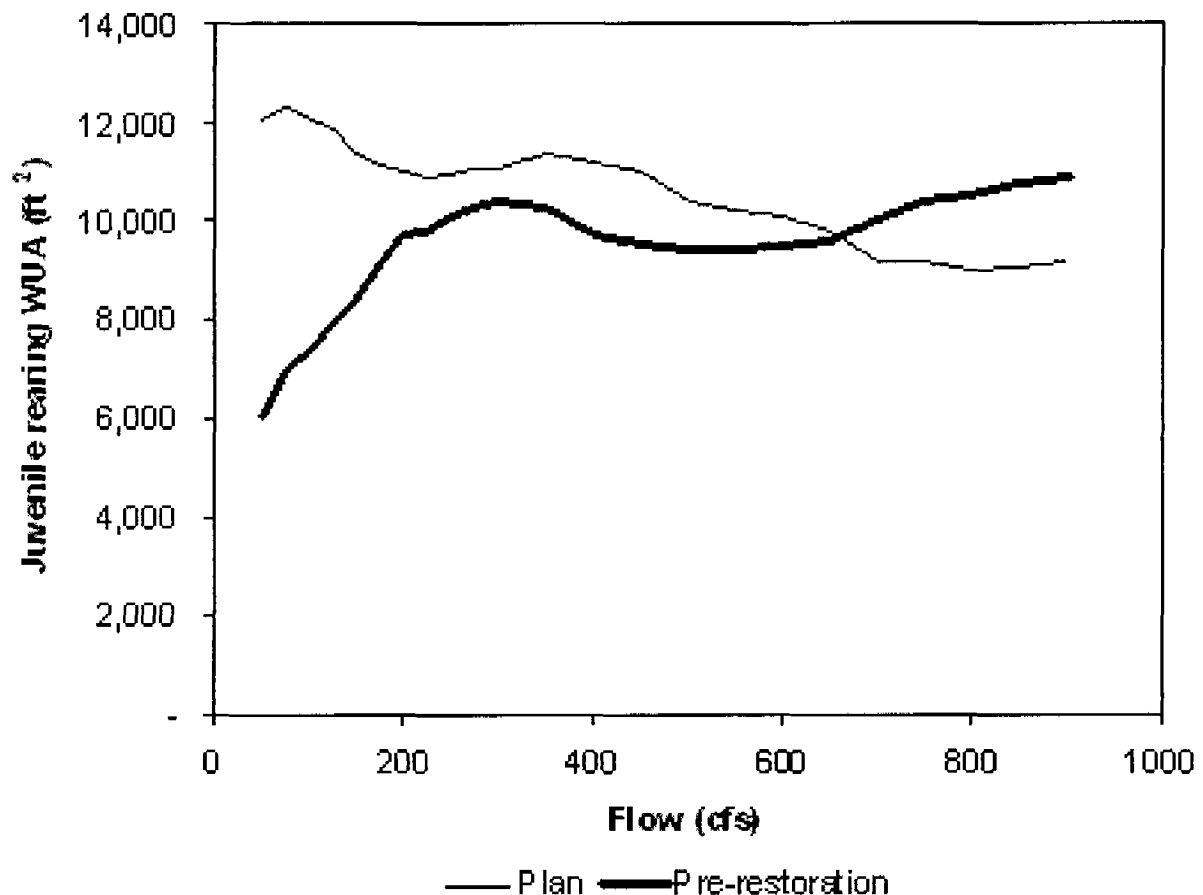


Figure 2
Fall-run Chinook Salmon Fry Rearing Flow-Habitat Relationships



The flow habitat relationships for fall-run chinook salmon juvenile rearing in the pre-restoration reach and the post-restoration plan are shown in Figure 3. These results indicate that the post-restoration plan will result in an increase in fall-run chinook salmon juvenile rearing habitat at flows ≤ 650 cfs, but a decrease in juvenile habitat at higher flows. As for fry, the latter effect could be alleviated by incorporating features such as large woody debris and small alcoves, which have high suitability for juvenile rearing, into the post-restoration plan.

Figure 3
Fall-run Chinook Salmon Juvenile Rearing Flow-Habitat Relationships



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APPENDIX A
RHABSIM WSEL CALIBRATION

Calibration Methods and Parameters Used

Study Site Pre-restoration	XS #	Flow Range	Calibration Flows	Method	Parameters
Site 1	1	50-900	141, 235	MANSQ	$\beta = 0.35$, CALQ = 141
Site 1	2	50-900	141, 235	MANSQ	$\beta = 0.39$, CALQ = 141
Site 2	1, 2	50-900	145, 244, 329, 425	IFG4	---
Site 3	1	150-900	2.7, 16.0, 27.3, 40.2	IFG4	---
Site 3	2	150-225	2.7, 16.0	MANSQ	$\beta = 0.46$, CALQ = 2.7
Site 3	2	250-900	16.0, 27.3, 40.2	IFG4	---
Site 4	1, 2	50-900	112, 216, 404	IFG4	---

Pre-restoration

Site 1

<u>XSEC</u>	BETA	%MEAN	Calculated vs Given Disch. (%)		Difference (measured vs. pred. WSELs)	
	<u>COEFF.</u>	<u>ERROR</u>	<u>141 cfs</u>	<u>235 cfs</u>	<u>141</u>	<u>235 cfs</u>
1	---	0.00	0.0	0.0	0.00	0.00
2	---	0.00	0.0	0.0	0.00	0.00

Site 2

<u>XSEC</u>	BETA	%MEAN	Calculated vs Given Disch. (%)				Difference (measured vs. pred. WSELs)			
	<u>COEFF.</u>	<u>ERROR</u>	<u>145 cfs</u>	<u>244 cfs</u>	<u>329 cfs</u>	<u>425 cfs</u>	<u>145 cfs</u>	<u>244 cfs</u>	<u>329 cfs</u>	<u>425 cfs</u>
1	2.68	2.17	2.0	2.9	1.5	2.3	0.02	0.03	0.02	0.03
2	2.44	0.82	0.4	0.1	1.7	1.1	0.00	0.00	0.02	0.01

Site 3

<u>XSEC</u>	BETA	%MEAN	Calculated vs Given Disch. (%)				Difference (measured vs. pred. WSELs)			
	<u>COEFF.</u>	<u>ERROR</u>	<u>2.7 cfs</u>	<u>16.0</u>	<u>27.3</u>	<u>40.2</u>	<u>2.7 cfs</u>	<u>16.0</u>	<u>27.3</u>	<u>40.2</u>
1	3.72	2.78	1.9	5.8	1.4	2.3	0.00	0.01	0.00	0.01
2	2.88	0.23		0.2	0.4	0.2		0.00	0.00	0.00

Site 3

<u>XSEC</u>	BETA	%MEAN	Calculated vs Given Disch. (%)		Difference (measured vs. pred. WSELs)	
	<u>COEFF.</u>	<u>ERROR</u>	<u>2.7 cfs</u>	<u>16.0</u>	<u>2.7 cfs</u>	<u>16.0</u>
2	---	0.00	0.0	0.0	0.00	0.00

Site 4

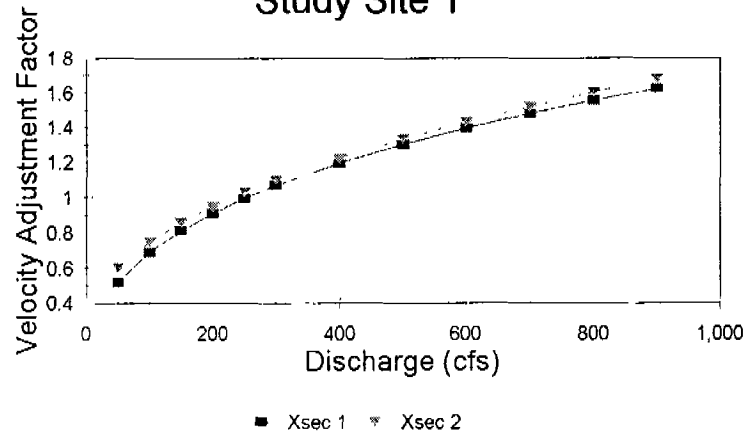
<u>XSEC</u>	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
	<u>COEFF.</u>	<u>ERROR</u>	<u>112 cfs</u>	<u>216 cfs</u>	<u>404 cfs</u>	<u>112 cfs</u>	<u>216 cfs</u>	<u>404 cfs</u>
1	3.99	5.19	4.5	8.2	3.2	0.03	0.05	0.03
2	2.71	4.45	3.7	7.0	2.9	0.03	0.08	0.03

APPENDIX B
VELOCITY ADJUSTMENT FACTORS

**PRE-RESTORATION
STUDY SITE 1**

**Clear Creek
Study Site 1**

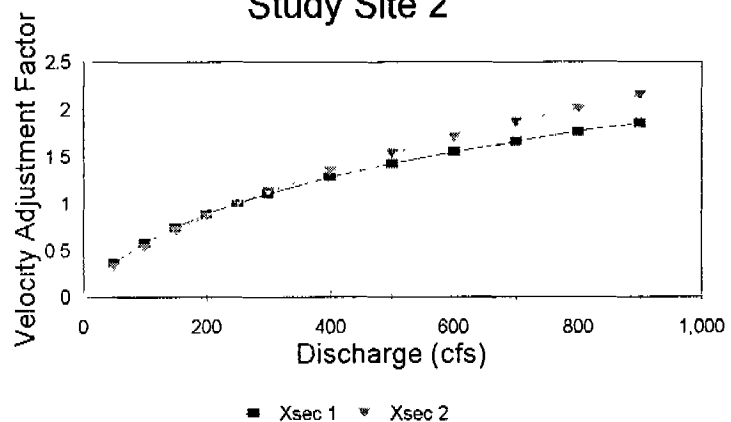
Discharge	Velocity Adjustment	
	Xsec 1	Xsec 2
50	0.52	0.60
100	0.69	0.75
150	0.81	0.86
200	0.91	0.95
250	0.99	1.03
300	1.07	1.10
400	1.19	1.22
500	1.30	1.33
600	1.39	1.43
700	1.48	1.52
800	1.56	1.60
900	1.63	1.68



**PRE-RESTORATION
STUDY SITE 2**

**Clear Creek
Study Site 2**

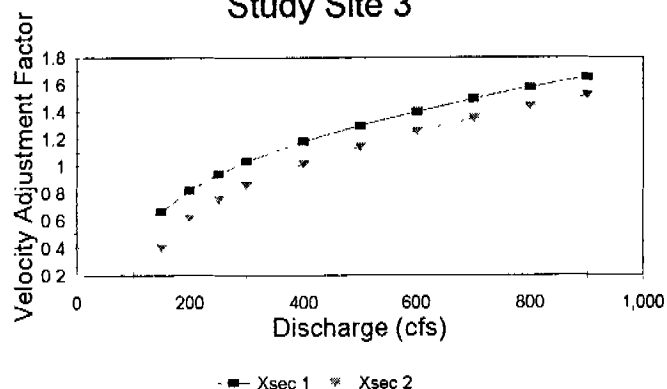
Discharge	Velocity Adjustment	
	Xsec 1	Xsec 2
50	0.37	0.32
100	0.58	0.54
150	0.75	0.71
200	0.89	0.87
250	1.01	1.00
300	1.11	1.13
400	1.28	1.35
500	1.43	1.54
600	1.55	1.71
700	1.67	1.87
800	1.77	2.01
900	1.86	2.15



PRE-RESTORATION STUDY SITE 3

Clear Creek Study Site 3

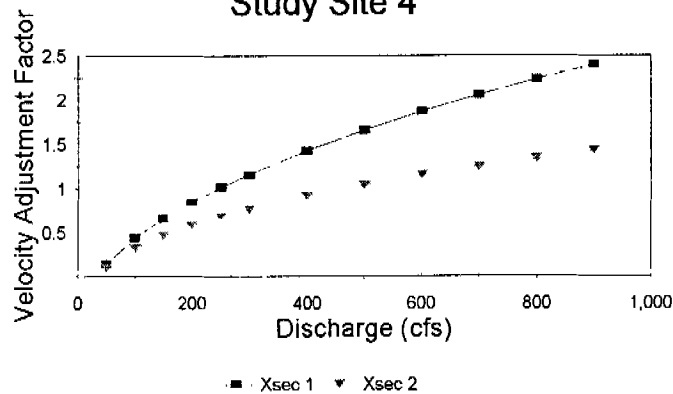
Velocity Adjustment Factors		
Discharge	Xsec 1	Xsec 2
150	0.66	0.40
200	0.82	0.61
250	0.94	0.75
300	1.03	0.85
400	1.18	1.01
500	1.30	1.14
600	1.40	1.25
700	1.49	1.35
800	1.58	1.44
900	1.65	1.52



PRE-RESTORATION STUDY SITE 4

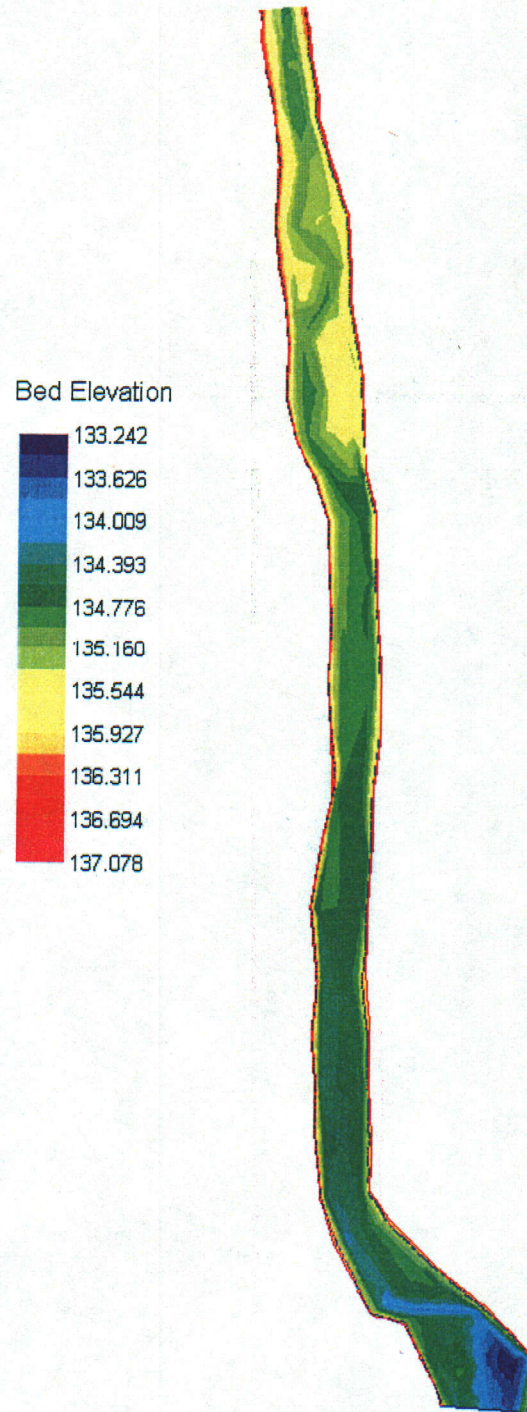
Clear Creek Study Site 4

Velocity Adjustment		
Discharge	Xsec 1	Xsec 2
50	0.14	0.11
100	0.44	0.32
150	0.66	0.47
200	0.85	0.58
250	1.01	0.68
300	1.16	0.76
400	1.42	0.91
500	1.66	1.04
600	1.87	1.15
700	2.06	1.25
800	2.23	1.34
900	2.40	1.43



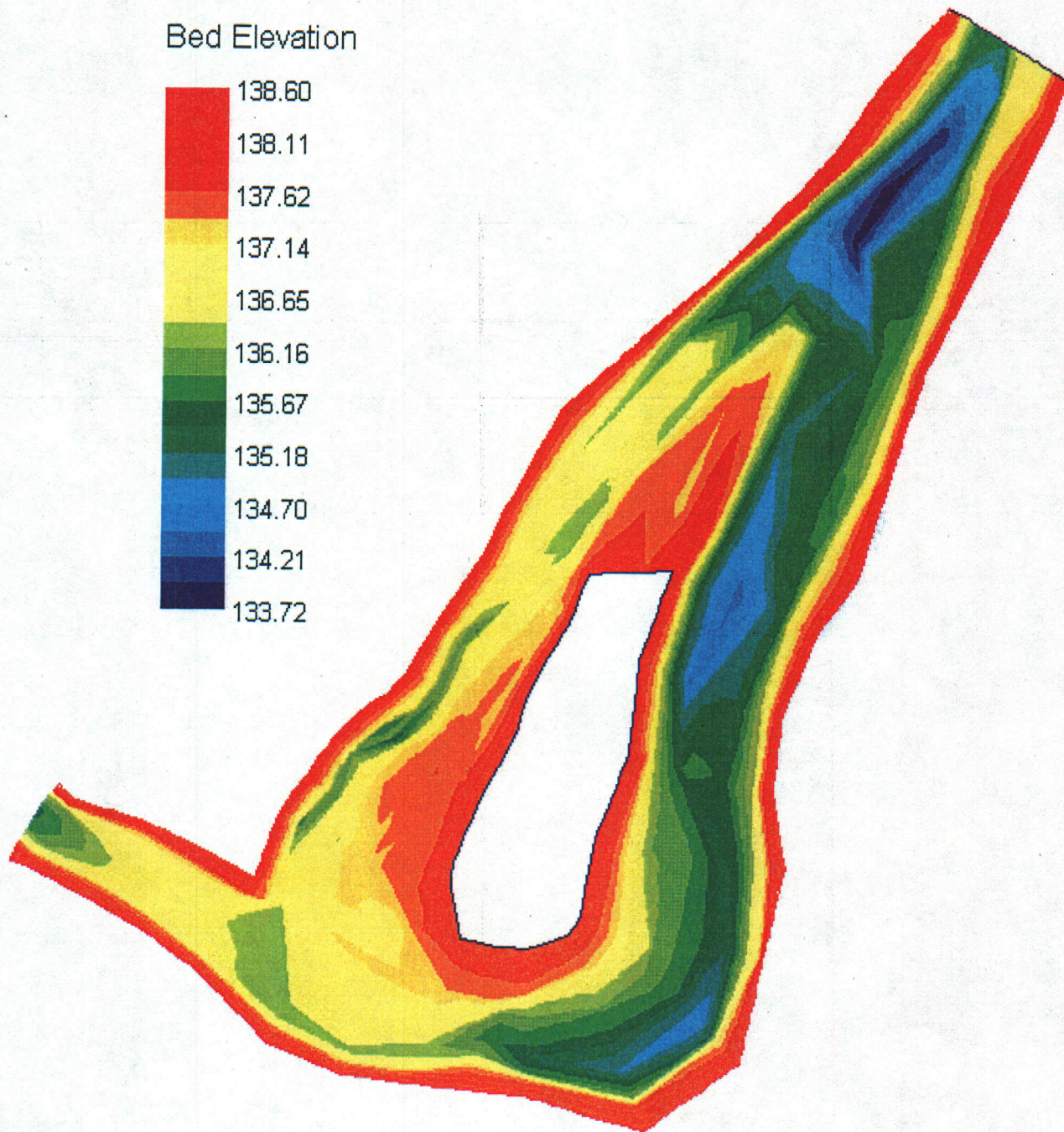
APPENDIX C
BED TOPOGRAPHY OF STUDY SITES

PRE-RESTORATION SITE 1



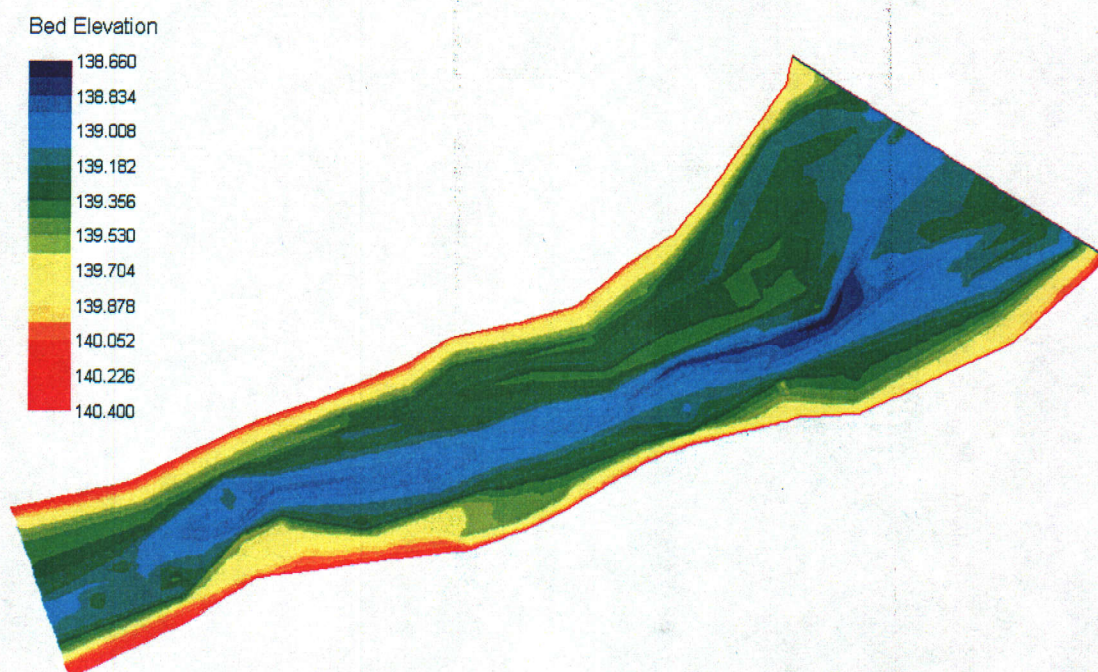
Units of Bed Elevation are meters.

PRE-RESTORATION SITE 2



Units of Bed Elevation are in meters.

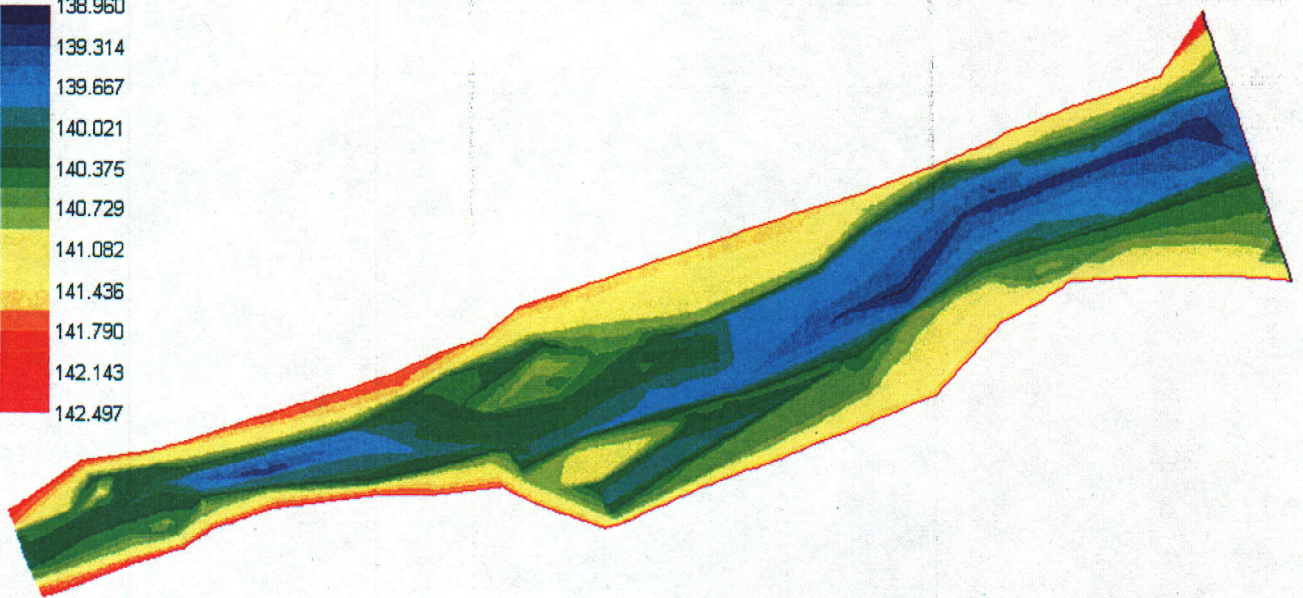
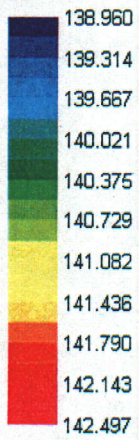
PRE-RESTORATION SITE 3



Units of Bed Elevation are in meters.

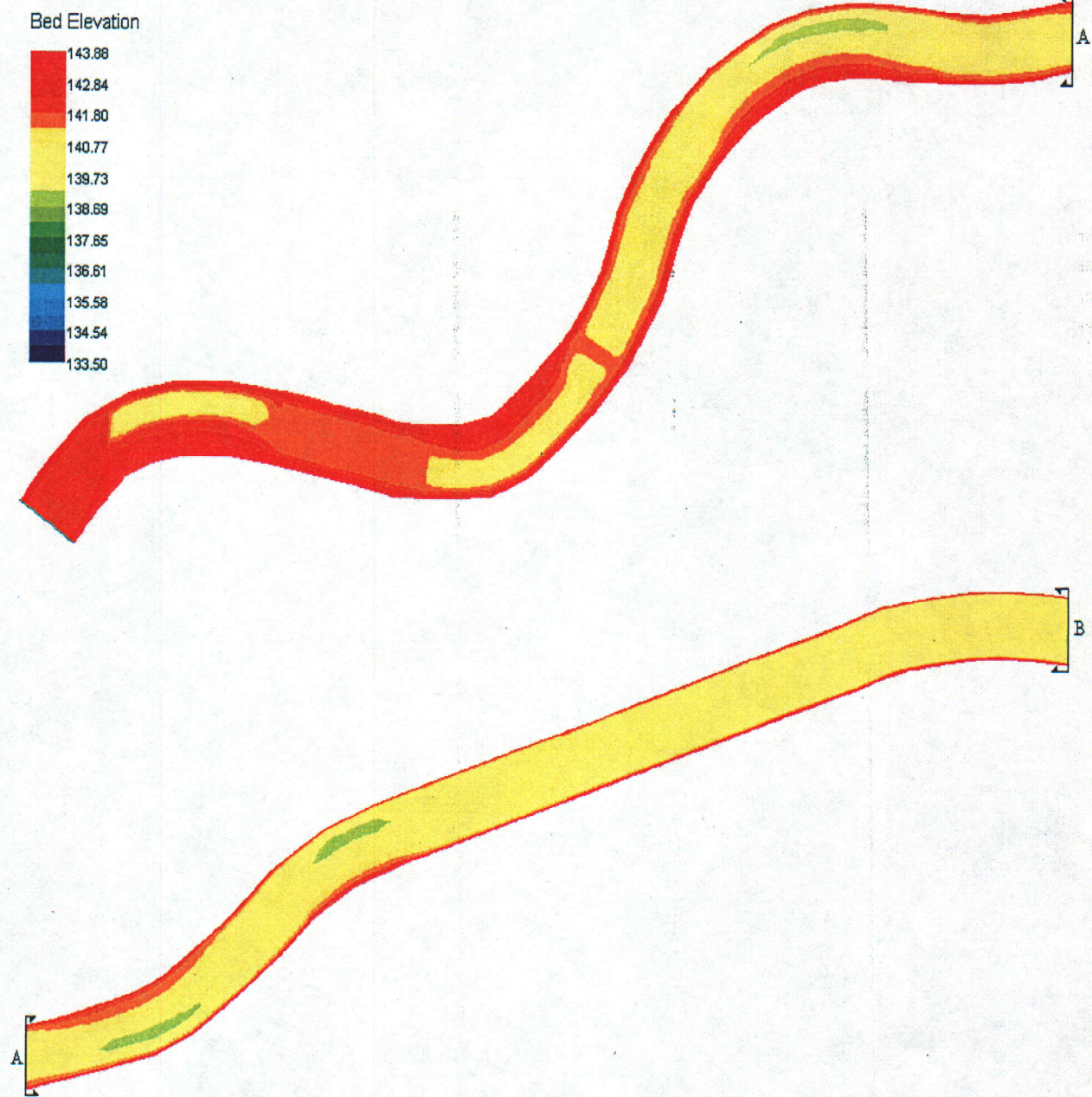
PRE-RESTORATION SITE 4

Bed Elevation

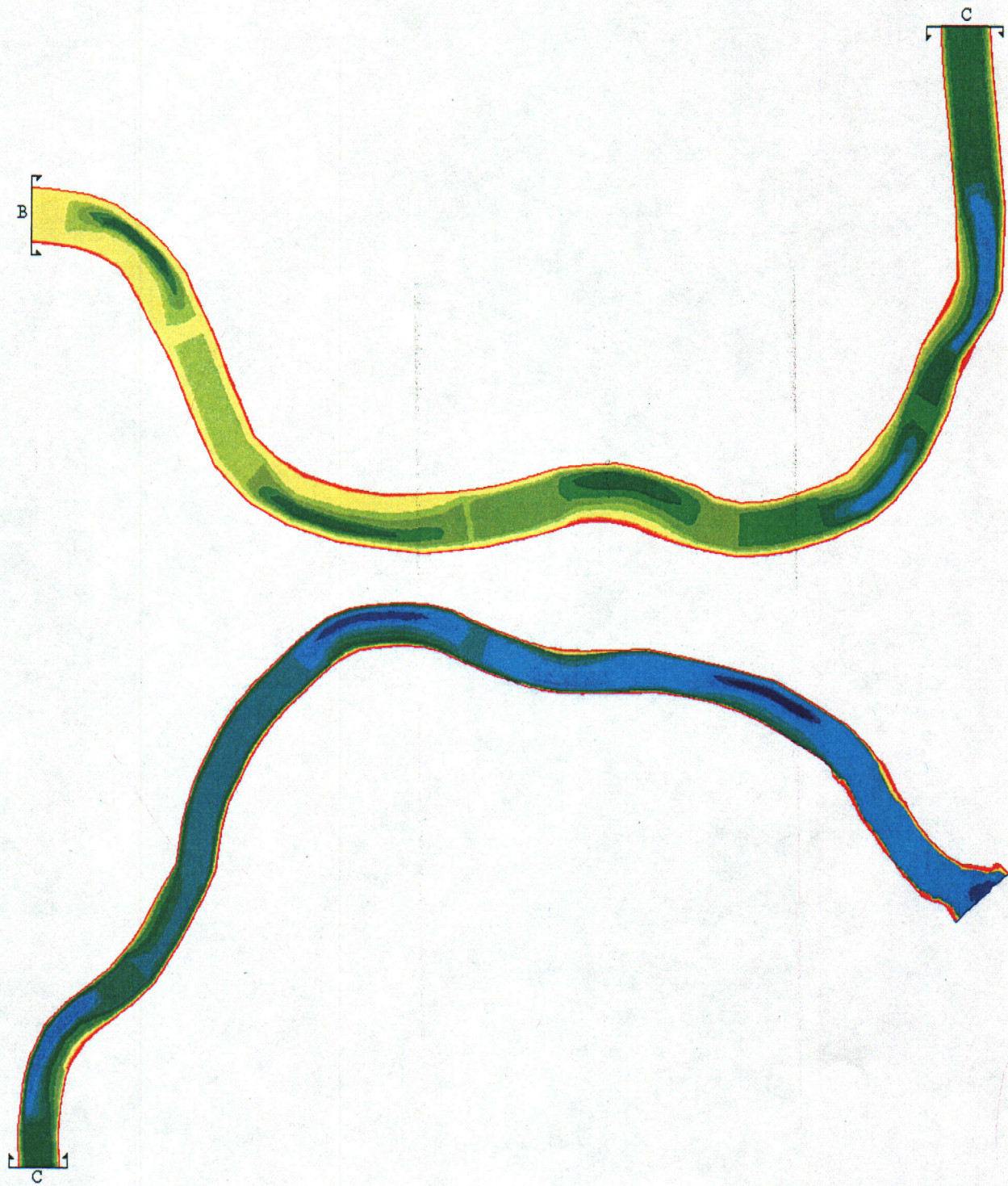


Units of Bed Elevation are in meters.

POST-RESTORATION PLAN



Units of Bed Elevation are in meters.



APPENDIX D

2-D WSEL CALIBRATION

Calibration Statistics

Site Name	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Site 1	87%	10860	0.30	0.19%	<.000001	1.21
Site 2	90%	18051	0.41	1.50%	<.000001	1.65
Site 3	98%	6620	0.30	0.59%	<.000001	0.66
Site 4	90%	11950	0.30	0.32%	<.000001	1.36
Plan	59%	34371	0.30	0.1%	.000005	2.00

Study Sites Cross Section 2

Difference (measured vs. pred. WSELs)

Site Name	Br Multiplier	Average	Standard Deviation	Maximum
Site 1	1.01	0.00	0.04	0.07
Site 2	0.3	0.04	0.01	0.05
Site 3	3.58	0.00	0.00	0.01
Site 4	0.98	0.04	0.06	0.10
Plan	3	0.12	0.02	0.17

APPENDIX E
VELOCITY VALIDATION STATISTICS

Measured Velocities less than 3 ft/s

Difference (measured vs. pred. velocities, ft/s)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Site 1	77	0.56	0.51	2.10
Site 2	87	0.32	0.39	2.62
Site 3	111	0.30	0.34	2.05
Site 4	93	0.34	0.39	2.06

Measured Velocities greater than 3 ft/s

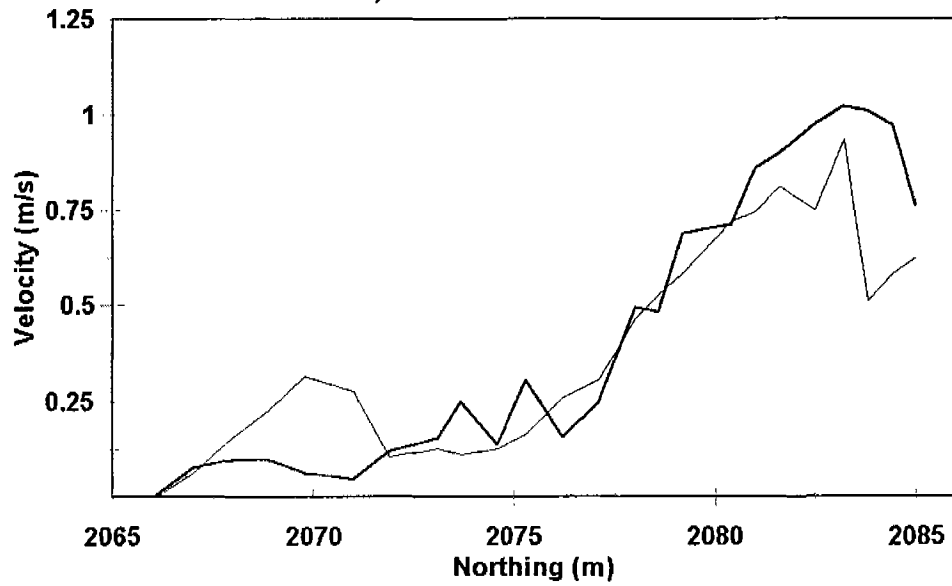
Percent Difference (measured vs. pred. velocities)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Site 1	19	15%	12%	37%
Site 2	1	3%	N/A	3%
Site 3	0	---	---	---
Site 4	5	40%	40%	96%

All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

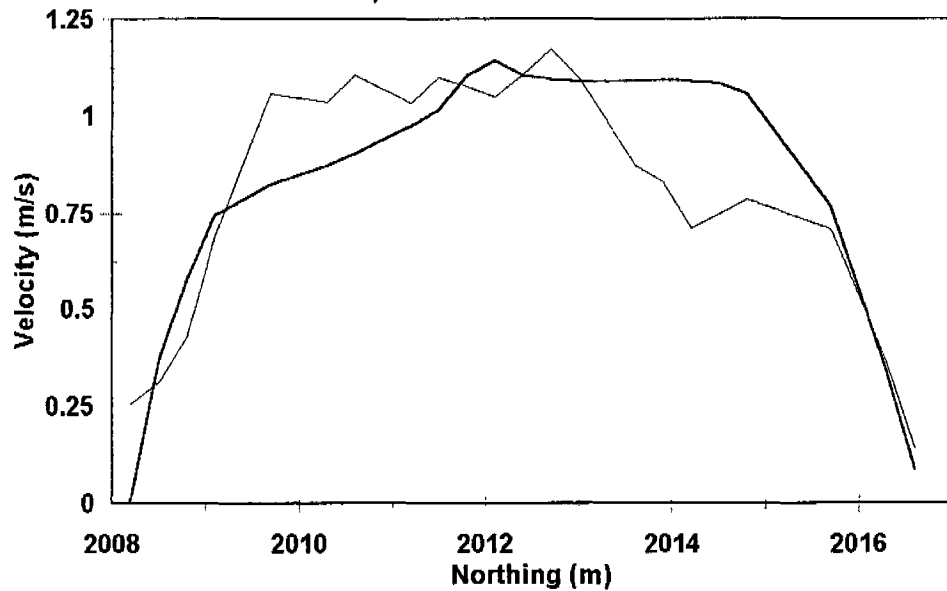
Site 1

Site 1 XS1, Clear Creek Q = 244 cfs



— 2-D Simulated Velocities — Measured Velocities

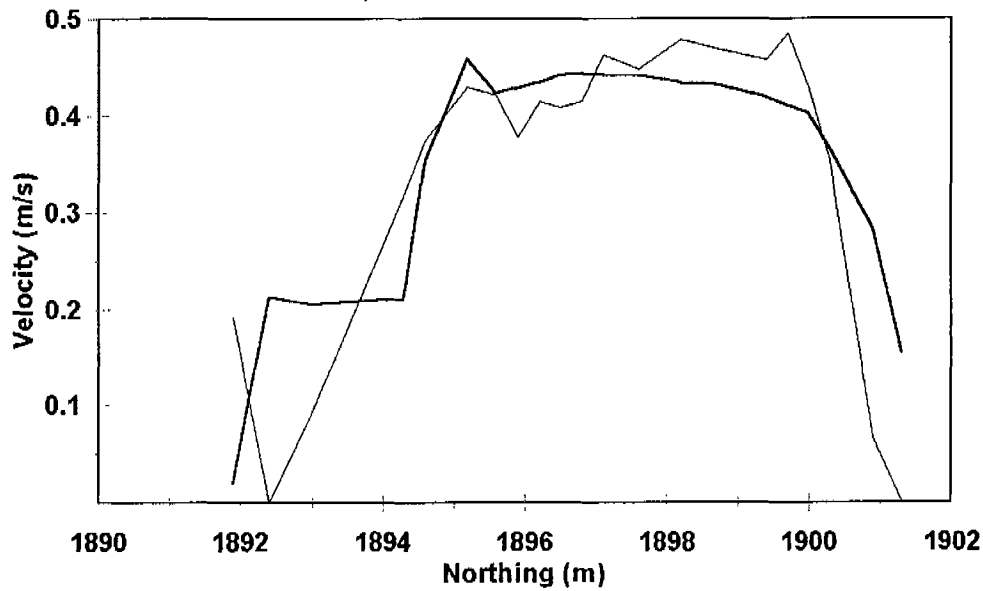
Site 1 XS2, Clear Creek Q = 244 cfs



— 2-D Simulated Velocities — Measured Velocities

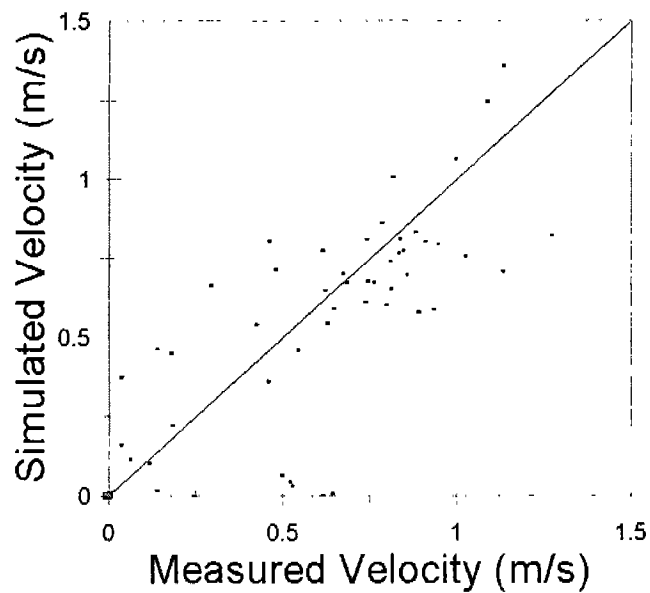
Site 1

Site 2 XS1, Clear Creek Q = 244 cfs



— 2-D Simulated Velocities — Measured Velocities

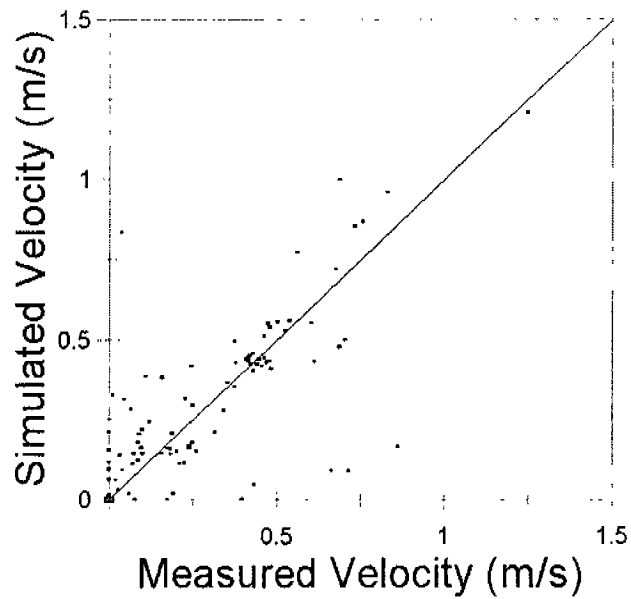
Between Transect Validation Velocities



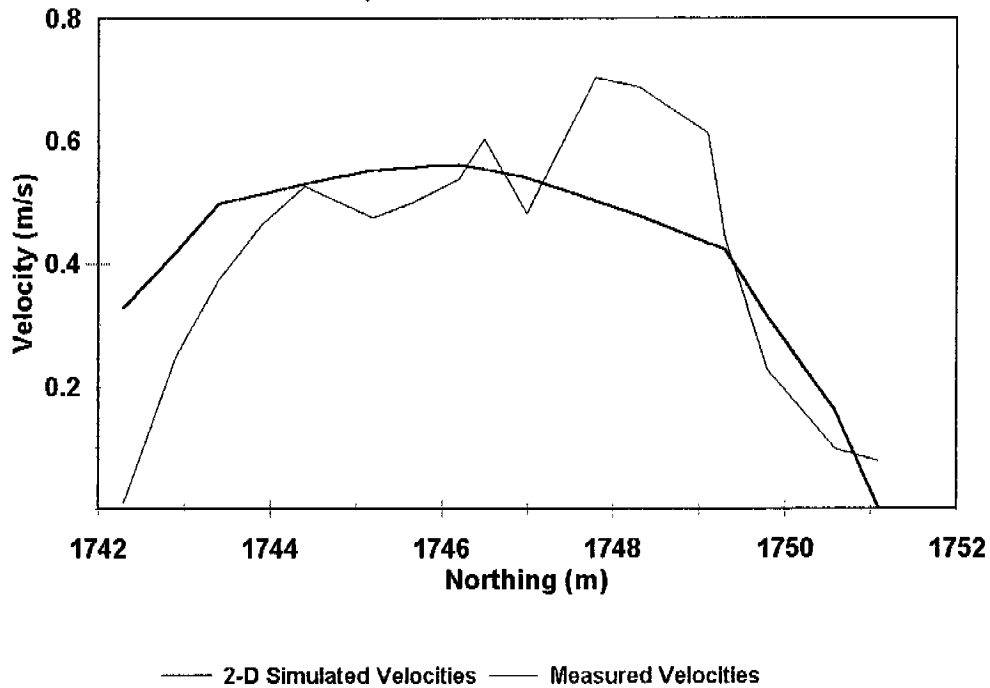
Si

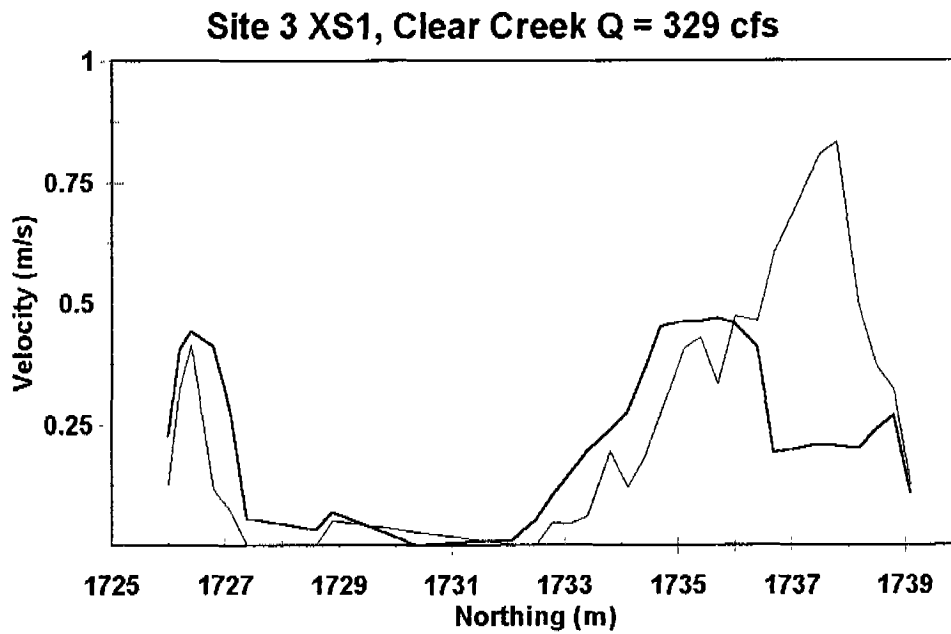
te 2

Site 2 All Validation Velocities



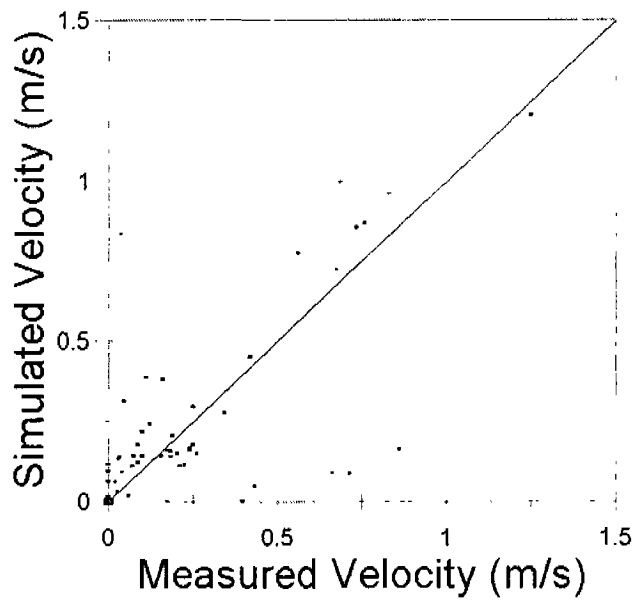
Site 2 XS2, Clear Creek Q = 244 cfs





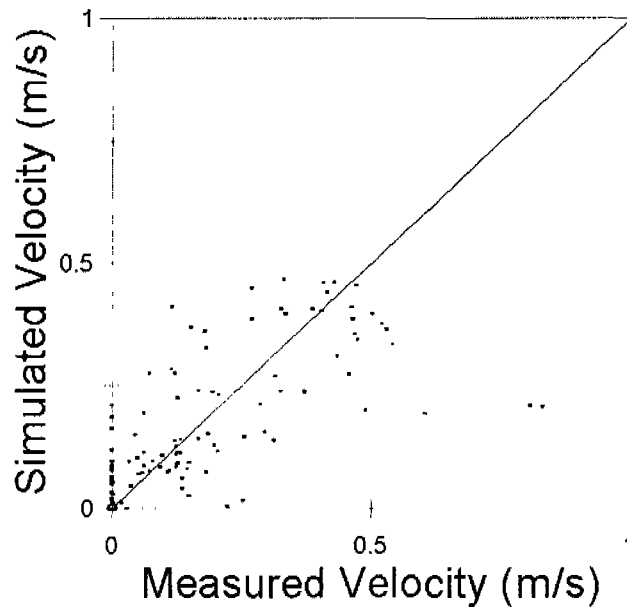
— 2-D Simulated Velocities — Measured Velocities

Between Transect Validation Velocities

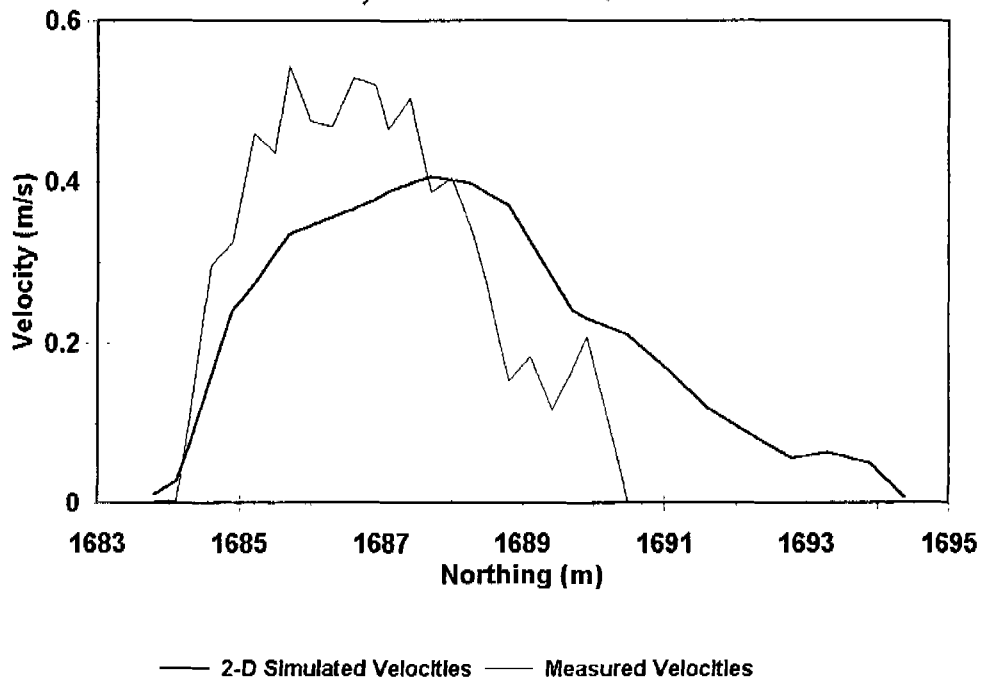


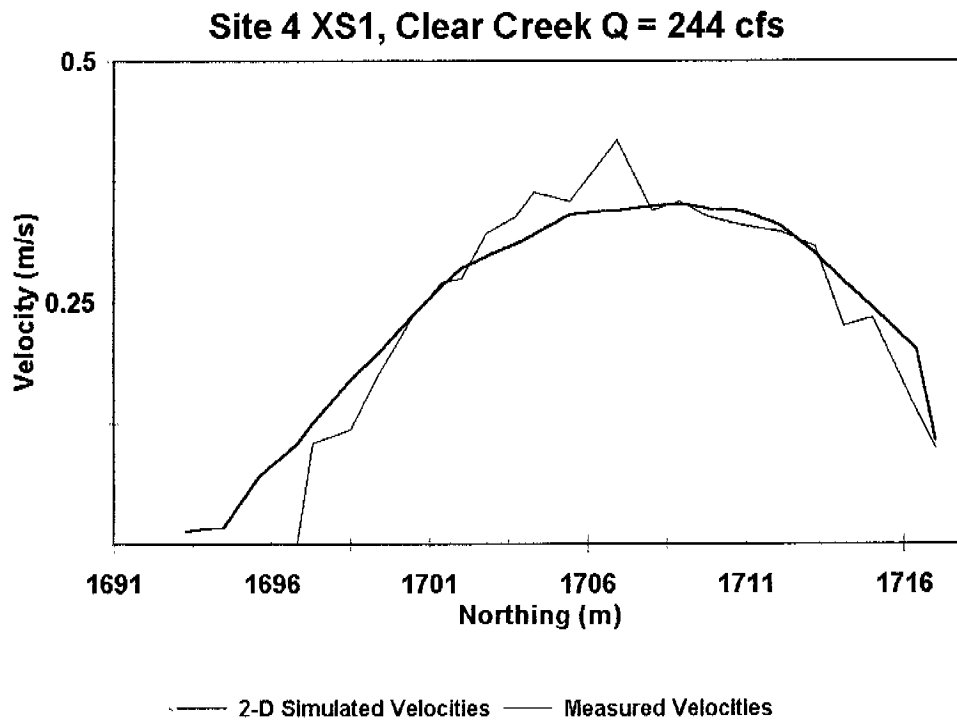
Site 3

Site 3 All Validation Velocities

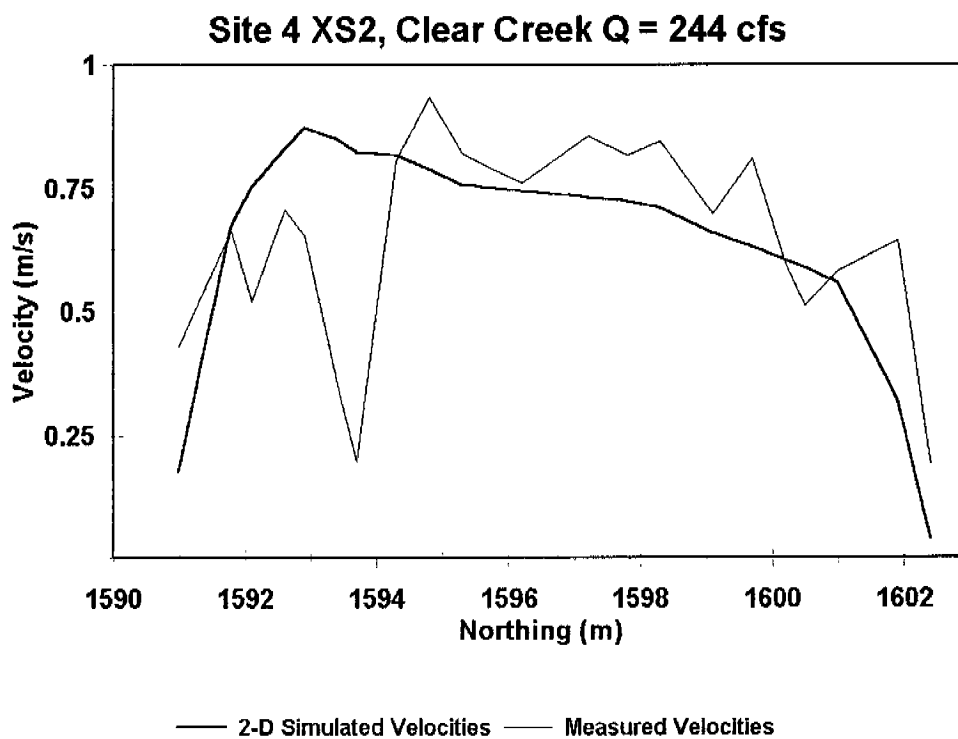


Site 3 XS2, Clear Creek Q = 329 cfs



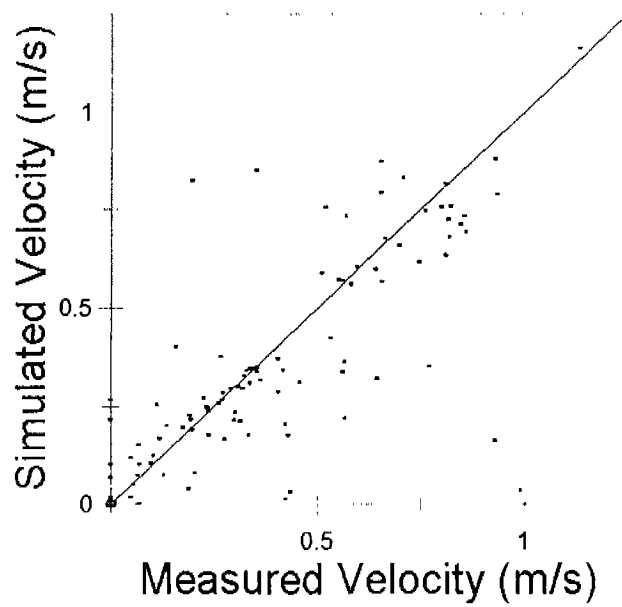


Site 4

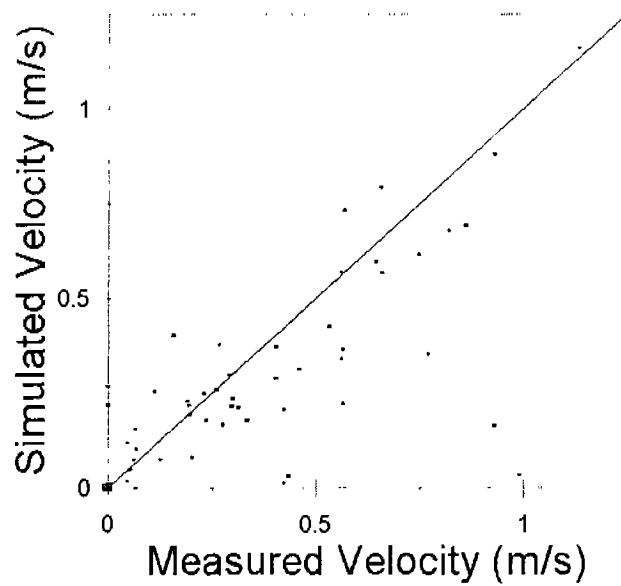


Site 4

All Validation Velocities



Site 4
Between Transect Validation Velocities



APPENDIX F
SIMULATION STATISTICS

Site 1

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.49%	.000001	1.36
75	1.08%	.000001	1.65
100	0.40%	.000001	1.55
125	0.29%	.000001	1.45
150	0.29%	< .000001	1.44
175	0.38%	< .000001	1.38
200	0.44%	.000003	2.30
225	0.49%	< .000001	1.80
250	0.59%	< .000001	1.56
275	0.56%	< .000001	1.28
300	0.52%	< .000001	1.08
350	0.36%	.000001	1.02
400	0.32%	.000001	1.03
450	0.39%	< .000001	1.02
500	0.35%	< .000001	1.01
550	0.30%	< .000001	1.00
600	0.31%	< .000001	1.03
650	0.31%	.000001	2.19
700	0.28%	< .000001	1.12
750	0.25%	< .000001	1.14
800	0.23%	.000003	1.14
850	2.52%	< .000001	1.19
900	0.19%	< .000001	1.21

Site 2

Flow (cfs)	Net Q	Sol Δ	Max F
50	2.86%	< .000001	1.21
75	1.90%	< .000001	1.14
100	1.43%	< .000001	1.20
125	0.86%	< .000001	1.12
150	0.71%	< .000001	1.07
175	1.00%	< .000001	1.08
200	0.88%	< .000001	1.09
225	0.94%	< .000001	1.22
250	0.85%	.000006	1.86
275	0.64%	< .000001	1.70
300	0.94%	< .000001	1.53
350	1.00%	< .000001	1.80
400	0.97%	< .000001	2.29
450	0.94%	< .000001	1.48
500	0.85%	< .000001	1.34
550	0.71%	< .000001	1.25
600	0.71%	< .000001	1.22
650	0.71%	< .000001	1.38
700	0.76%	< .000001	1.42
750	0.84%	.000005	1.39
800	1.09%	.000003	1.36
850	1.04%	.000004	1.33
900	0.94%	.000002	1.35

Site 3

Flow (cfs)	Net Q	Sol Δ	Max F
150	8.30%	< .000001	0.23
175	4.74%	< .000001	0.28
200	3.15%	< .000001	0.46
225	1.84%	< .000001	0.49
250	1.89%	< .000001	0.52
275	1.05%	< .000001	0.55
300	0.30%	< .000001	0.57
350	0.58%	< .000001	0.62
400	0.05%	< .000001	0.62
450	0.16%	< .000001	0.64
500	0.05%	< .000001	0.65
550	0.19%	< .000001	0.66
600	0.11%	< .000001	0.66
650	0.25%	< .000001	0.66
700	0.32%	< .000001	0.67
750	0.42%	< .000001	0.66
800	0.39%	< .000001	0.67
850	0.44%	< .000001	0.66
900	0.58%	< .000001	0.66

Site 4

Flow (cfs)	Net Q	Sol Δ	Max F
50	0.80%	< .000001	0.79
75	0.09%	< .000001	0.72
100	0.59%	.000004	0.71
125	3.47%	.000006	1.34
150	0.12%	< .000001	1.78
175	0.10%	.000008	1.74
200	0.08%	.000002	1.61
225	0.07%	< .000001	1.49
250	0.14%	.000008	1.45
275	0.28%	.000005	1.40
300	0.26%	.000001	1.39
350	0.22%	.000004	1.23
400	0.28%	< .000001	1.76
450	0.25%	< .000001	1.66
500	0.22%	< .000001	1.56
550	0.32%	< .000001	1.48
600	0.33%	.000001	1.40
650	0.28%	< .000001	1.33
700	0.26%	.000007	1.34
750	0.28%	.000003	1.35
800	0.33%	.000003	1.36
850	0.34%	.000003	1.36
900	0.32%	< .000001	1.36

Post-restoration Plan

Flow (cfs)	Net Q	Sol Δ	Max F
50 ²⁰	89.7%	.000006	1.89
50 ²¹	7.2%	< .000001	1.90
75 ¹⁸	77.7%	.000003	3.89
75 ¹⁹	7.6%	.000003	2.46
100	0.6%	.000009	2.30
125	0.4%	< .000001	3.17
150	0.4%	< .000001	2.65
175	0.3%	< .000001	2.34
200	0.2%	.000002	2.17
225	0.2%	.000002	2.07
250	0.2%	.000002	2.01
275	0.1%	.000005	1.98
300	0.1%	.000003	1.94
350	0.2%	.000007	1.82
400	0.3%	.000006	1.76
450	0.4%	.000007	1.77
500	0.1%	.000001	1.78
550	0.1%	.000002	1.78
600	0.05%	.000001	1.79
650	0.03%	.000002	1.74
700	0.03%	.000002	1.77
750	0.02%	.000002	1.79
800	0.03%	.000003	1.82
850	0.05%	.000003	1.68
900	0.02%	.000004	1.65

²⁰ Using the fixed downstream water surface elevation boundary condition.

²¹ Using the variable downstream water surface elevation boundary condition.

APPENDIX G
FINAL CLEAR CREEK FALL-RUN CHINOOK SALMON
SPAWNING AND REARING HSC

FALL-RUN CHINOOK SALMON SPAWNING HSC

<u>Water Depth (ft)</u>	<u>SI Value</u>	<u>Water Velocity (ft/s)</u>	<u>SI Value</u>	<u>Substrate Composition</u>	<u>SI Value</u>
0.00	0	0.00	0	0.1	0
0.40	0	0.31	0	1	0
0.50	0.22	0.32	0.08	1.2	0.33
0.62	0.30	0.40	0.11	1.3	0.91
0.78	0.41	0.52	0.17	2.3	0.96
0.93	0.54	0.72	0.30	2.4	1.00
1.08	0.67	0.85	0.41	3.4	0.76
1.24	0.79	0.97	0.54	3.5	0.53
1.39	0.89	1.23	0.78	4.5	0.35
1.54	0.96	1.36	0.88	4.6	0.16
1.70	1.00	1.55	0.98	6.8	0
1.85	1.00	1.68	1.00	100	0
48	0	1.75	1.00		
100	0	1.88	0.97		
		1.94	0.95		
		2.07	0.89		
		2.33	0.73		
		2.58	0.55		
		2.84	0.39		
		3.10	0.27		
		3.29	0.20		
		3.36	0.19		
		3.48	0.15		
		3.93	0.08		
		4.32	0.05		
		4.51	0.05		
		4.58	0.04		
		5.79	0.04		
		5.8	0		
		100	0		

FALL-RUN CHINOOK SALMON FRY REARING HSC

Water		Water		Cover	Adjacent		
Velocity (ft/s)	SI Value	Depth (ft)	SI Value		SI Value	Velocity (ft/s)	SI Value
0	0.86	0	0.00	0	0.00	0	0.56
0.10	0.96	0.1	0.00	0.1	0.24	1.83	1.00
0.20	1.00	0.2	0.82	1	0.24	100	1.00
0.25	1.00	0.7	0.94	2	0.24		
0.40	0.95	1.3	1.00	3	0.24		
0.60	0.77	1.8	1.00	3.7	1.00		
0.90	0.40	2.5	0.93	4	1.00		
1.10	0.22	3.0	0.85	4.7	1.00		
1.30	0.13	5.0	0.37	5	1.00		
1.60	0.06	6.0	0.19	5.7	1.00		
2.54	0.02	7.0	0.10	7	0.24		
2.55	0.00	8.0	0.05	8	1.00		
100	0.00	10.0	0.02	9	0.24		
		13.0	0.02	9.7	0.24		
		15.0	0.04	10	0.24		
		16.5	0.04	100	0.00		
		18.6	0.01				
		18.7	0.00				
		100	0.00				

FALL-RUN CHINOOK SALMON JUVENILE REARING HSC

Water		Water		Cover	Adjacent		
Velocity (ft/s)	SI Value	Depth (ft)	SI Value		SI Value	Velocity (ft/s)	SI Value
0	0.47	0	0.00	0	0.00	0	0.09
0.20	0.85	0.3	0.00	0.1	0.24	4.14	1.00
0.30	0.96	0.4	0.41	1	0.24	100	1.00
0.40	1.00	1.6	0.90	2	0.24		
0.50	0.98	2.0	0.98	3	0.24		
0.60	0.91	2.2	1.00	3.7	1.00		
1.10	0.35	2.5	1.00	4	1.00		
1.30	0.21	3.0	0.94	4.7	1.00		
1.50	0.13	3.5	0.84	5	1.00		
1.70	0.09	5.5	0.32	5.7	1.00		
2.10	0.06	6.5	0.17	7	0.24		
2.60	0.08	8.0	0.07	8	1.00		
2.75	0.10	9.5	0.04	9	0.24		
3.93	0.00	10.5	0.03	9.7	0.24		
100	0.00	13.5	0.03	10	0.24		
		17.5	0.07	100	0.00		
		19.0	0.07				
		20.0	0.06				
		22.0	0.02				
		23.7	0.01				
		23.8	0.00				
		100	0.00				

APPENDIX H HABITAT MODELING RESULTS

Fall-run chinook salmon spawning WUA (ft²)

Flow (cfs)	Clear 1	Clear 2	Clear 3	Clear 4	Pre-Restoration Total	Post-Restoration Plan
50	14,565	1622	0	743.6	32,519	67,812
75	18,293	2178	0	2670	45,383	114,700
100	19,488	2765	0	4134	52,020	158,003
125	18,917	3123	0	4570	52,195	188,572
150	17,696	3659	43.49	4635	50,756	206,139
175	15,820	4065	137.7	4593	47,741	214,868
200	13,772	4276	264.5	4631	44,548	214,685
225	12,204	4272	408.9	4707	42,029	209,594
250	10,566	4318	562.1	4759	39,476	201,715
275	9253	4288	718.1	4834	37,498	193,481
300	8096	4244	865.6	4914	35,841	183,072
350	6254	4292	1126	5025	33,448	162,653
400	4952	4298	1242	5002	31,433	143,913
450	4007	4310	1436	4873	29,994	127,659
500	3330	4478	1591	4590	28,776	111,331
550	2797	4633	1717	4260	27,571	99,458
600	2415	4650	1819	3842	26,090	88,802
650	2121	4472	1902	3472	24,436	79,427
700	1911	4204	1965	3095	22,702	72,096
750	1734	4026	2018	2826	21,420	66,607
800	1600	3889	2059	2684	20,608	62,032
850	1489	3547	2078	2315	18,738	58,179
900	1390	3329	2105	2042	17,437	54,863

Fall-run chinook salmon fry rearing WUA (ft²)

Flow (cfs)	Clear 1	Clear 2	Clear 3	Clear 4	Pre-Restoration Total	Post-Restoration Plan
50	3767	2857	0	6834	28,259	51,085
75	3657	2936	0	7224	29,262	45,434
100	3747	3027	0	7177	29,946	41,495
125	3836	3297	0	7410	31,726	38,707
150	3829	3482	755.3	7433	34,112	37,017
175	3815	3686	938.1	7504	35,761	34,853
200	3729	3998	983.5	7375	36,263	33,443
225	3710	4192	1050	7048	35,969	32,205
250	3525	4222	1068	6879	35,339	31,065
275	3434	4213	1087	6855	35,230	29,924
300	3338	4105	1092	6882	35,057	29,461
350	3178	3677	1068	6885	34,054	29,278
400	3128	3530	1076	6813	33,728	29,062
450	3122	3148	1043	6783	32,834	28,793
500	3204	2720	1005	7012	32,934	28,955
550	3384	2577	982.3	7357	33,934	29,127
600	3521	2631	969.0	7869	35,632	29,213
650	3807	2843	957.0	8393	38,101	29,450
700	3965	3100	924.3	8675	39,595	30,365
750	4007	3498	898.5	8827	40,735	31,506
800	3980	4046	860.3	8908	41,752	32,367
850	4025	4272	843.1	9028	42,343	33,260
900	4025	4503	790.3	9067	42,490	33,982

Fall-run chinook salmon juvenile rearing WUA (ft²)

Flow (cfs)	Clear 1	Clear 2	Clear 3	Clear 4	Pre-Restoration Total	Post-Restoration Plan
50	978.0	1463	0	1022	6018	12,099
75	1002	1627	0	1495	6995	12,292
100	1051	1694	0	1679	7385	12,045
125	1116	1746	0	1826	7937	11,873
150	1180	1790	99.50	1841	8394	11,420
175	1250	1828	159.3	1974	9221	11,151
200	1312	1889	194.4	2025	9782	11,022
225	1375	1942	222.5	1910	9840	10,925
250	1396	2003	231.4	1901	10,105	10,936
275	1413	2051	242.2	1896	10,302	11,054
300	1416	2081	256.9	1891	10,432	11,130
350	1367	2069	274.4	1865	10,283	11,377
400	1232	2025	284.7	1782	9761	11,227
450	1194	1954	294.9	1785	9565	10,990
500	1176	1841	301.5	1787	9381	10,419
550	1152	1781	305.6	1859	9419	10,226
600	1169	1766	305.1	1912	9499	10,064
650	1232	1783	306.2	1941	9611	9784
700	1312	1847	310.4	1998	10,019	9192
750	1440	1876	315.9	2030	10,379	9192
800	1571	1936	319.1	2021	10,561	9009
850	1707	1953	322.2	2026	10,799	9031
900	1813	1999	320.7	2004	10,920	9171